OPTIMIZATION OF THE ELECTRICAL DISCHARGE MACHINING PERFORMANCE ON TITANIUM ALLOY BY USING STATISTICAL METHOD

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Thesis submitted in fulfilment of the requirements

for the award of the degree of

Bachelor in Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

JUNE 2013

ABSTRACT

This report will discuss about the aim of this project were to optimize the objective of machining parameters on Titanium alloy workpiece by using the Taguchi method. The machining characteristics such as the material removal rate (MRR), electrode wear rate (EWR), surface roughness (SR) have been recorded in and the analysis of the machining parameters using the copper as a tool or electrode at the cathode and titanium alloy as a workpiece at the anode with the two polarities selected. The method during this project is Design of experiment (DOE) which is an Analysis of Variance (ANOVA) and also the Taguchi method that has been used to define the optimization of single response characteristics. It is called as Taguchi Method that use to formulate the experimental layout, to analysis the effect of each parameter on the machining characteristics and to predict the optimal choice for each EDM parameter. The other, the result from the analysis using Taguchi method will compare with an RSM method to find the best DOE that can be used and from all comparison the most of the best method for the machining performance is RSM method. Thus, higher MRR from the analysis will give the result for the negative and positive copper which is at positive copper higher MRR suggested at peak current (22A), pulse-on time (180µs), pulse-off time (180µs) and servo voltage (95V), lower EWR at peak current (22A), pulse-on time (95µs), pulse-off time (240µs) and servo voltage (85V), and better SR at peak current (22A), pulse-on time (180µs), pulse-off time (240µs) and servo voltage (95V) is the goals and it taken separately in different phase of work during the experiment. The result of the negative copper also has been analysis and the best machining parameter for it also have been selected with the negative copper also come with the best combination of the parameter to optimize the machining performance where for the MRR the best combination of the parameter is at peak current (22A), pulse-on time (180µs), pulse-off time (240µs) and servo voltage (85V), the EWR at peak current (15A), pulse-on time (95µs), pulse-off time (180µs) and servo voltage (105V) is the best level and for the SR, the best combination at peak current (22A), pulse-on time (265µ), pulse-off time (240µs) and servo voltage (95V) is the best level of the parameter of the machining performance. The comparison between Taguchi and RSM method show that the most method that suitable to use is RSM method.

ABSTRAK

Laporan ini akan membincangkan tentang matlamat projek ini adalah untuk mengoptimumkan objektif parameter mesin pada Titanium aloi bahan kerja dengan menggunakan kaedah Taguchi. Ciri-ciri pemesinan seperti kadar penyingkiran bahan (MRR), kadar memakai elektrod (EWR), kekasaran permukaan (SR) telah direkodkan di dalam dan analisis parameter pemesinan menggunakan tembaga sebagai alat atau elektrod pada katod dan aloi titanium sebagai bahan kerja pada anod dengan dua polariti dipilih. Kaedah semasa projek ini adalah reka bentuk eksperimen (DOE) yang merupakan Analisis Varian (ANOVA) dan juga kaedah Taguchi yang telah digunakan untuk menentukan pengoptimuman ciri-ciri tindak balas tunggal. Ia dipanggil sebagai Taguchi Kaedah yang digunakan untuk merangka susun atur eksperimen, analisis kesan setiap parameter kepada ciri-ciri mesin dan untuk meramalkan pilihan optimum bagi setiap parameter EDM. Yang lain, hasil daripada analisis menggunakan kaedah Taguchi akan membandingkan dengan kaedah RSM untuk mencari DOE terbaik yang boleh digunakan dan dari perbandingan yang paling kaedah yang terbaik untuk prestasi mesin adalah kaedah RSM. Oleh itu, MRR lebih tinggi daripada analisis akan memberikan hasil untuk tembaga negatif dan positif yang pada tembaga positif MRR yang lebih tinggi yang disyorkan semasa di puncak (22A), nadi pada masa (180µs), masa nadi-off (180µs) dan servo voltan (95V), EWR lebih rendah pada masa puncak (22A), nadi pada masa (95µs), masa nadi-off (240µs) dan voltan servo (85V), dan SR yang lebih baik pada masa puncak (22A), nadi pada masa (180µs), masa nadi-off (240µs) dan voltan servo (95V) adalah matlamat dan ia diambil secara berasingan dalam fasa kerja yang berbeza dalam eksperimen. Hasil tembaga negatif juga telah analisis dan parameter pemesinan yang terbaik untuk ia juga telah dipilih dengan tembaga negatif juga datang dengan kombinasi yang terbaik parameter untuk mengoptimumkan prestasi pemesinan di mana untuk MRR gabungan terbaik parameter adalah semasa di puncak (22A), nadi pada masa (180µs), masa nadi-off (240µs) dan voltan servo (85V), EWR di puncak semasa (15A), nadi pada masa (95µs), masa nadi-off (180µs) dan voltan servo (105V) adalah tahap terbaik dan bagi SR, kombinasi yang terbaik pada masa puncak (22A), nadi pada masa (265µ), masa nadi-off (240µs) dan voltan servo (95V) adalah tahap terbaik parameter prestasi pemesinan. Perbandingan antara Taguchi dan kaedah RSM menunjukkan bahawa kaedah yang paling sesuai digunakan adalah kaedah RSM.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLE

LIST OF SYMBOL

μm	micrometre
μs	microsecond
mm^3/min	Millimetre per minutes
%	percentage
A	Ampere
V	volt

LIST OF ABBREVIATIONS

EDM	Electrical Discharge Machining
MRR	Material Removal Rate
EWR	Electrode Wear Rate
SR	Surface Roughness
S/N ratio	Signal of Noise
OA	Orthogonal Array
RSM	Response Surface Methodology
ANOVA	Analysis of Variance
DOE	Design of Experiment

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The classical experimental methods that have design before are too complex and difficult to use. The Taguchi method approach is totally based on statistical design of experiments and this can economically satisfy the needs of problem solving and product/process design optimization (J.A. Ghani et al., 2004). Besides that, it will have more cost and time to complete the experiment if the parameter that been use are many. In the study previously, the Taguchi method is the powerful tool for designing the parameter to get the performance characteristic (N. Tosun et.al., 2004). Therefore the Taguchi methods have been designed for the use of the entire process parameter space but with the small number of experiments. Taguchi method is the other way to design the factorial experiment possesses some advantage such as much quantitative information can be extruded by only a few experiment trail (A. Adnani et al., 2010). The Taguchi method that has been selected for the analysis that will study known as statistical design of the experiment for studying the optimization of the EDM machining performance characteristic with the factor and their level regarding the Orthogonal Array (OA) standard to identify the better input of parameters.

From the design of the Taguchi method, the result will have to estimate using the computer simulation programming on the Minitab software. The software will have the major tools such as the signal to noise and the Orthogonal Array also the ANOVA. The signal to noise is the tool to measure the quality with emphasis on the variation and orthogonal array is accommodating many design factors simultaneously (J.A. Ghani et al., 2004). Moreover, a study of the optimization of the EDM machining characteristic also makes the comparison with the Response Surface Methodology (RSM) where the RSM also one of the methods of design of the experiment. RSM is also known as a collection of statistical and mathematical methods that is useful for the modeling and analyzing engineering problems (N. Aslan., 2007).

Electrical Discharge Machine (EDM) is the one of the machining that used for hard material or for the material that would impossible to machine with traditional technique. This is because, the traditional machining is ineffective. Besides that, the important thing that has remembered about the EDM machining is that it will only work with the materials that are electrically conductive. Electrical Discharge Machine (EDM) is a controlled the metal - removal process that used to remove the metal by producing a rapid series of repetitive electrical discharge between the product and the electrode. EDM process now is the process that has good accuracy and precision with no direct contact between the electrodes or called as the tool with the product therefore it will not have problem involve related to mechanical stress exerted to the product. Since the EDM process does not involve mechanical energy, the removal rate is not affected by hardness, strength or toughness (S.H. Lee and X.P Li, 2001). This method can be used with any other metal or metal alloy such as titanium, hastelloy, kovar , and inconel.

The Electrical Discharge Machine (EDM) has some limitations. The main limitation of the process such as it can only be employed in electrically conductive materials as known before. Besides that, the material removal rate is low and the process overall is slow compared to conventional machining processes. The EDM process usually uses the electrode that made of graphite, brass, copper and copper tungsten alloys (Yan et al., 2000). Therefore, a comprehensive study of the effect parameter such as discharge current, polarity, discharge voltage and others on the machining characteristics is of great significance and could be of necessity.

1.2 PROJECT BACKGROUND

The case studies for this project to find the solution for the problem statement. The maximizing the result for the material removal rate (MRR), minimizing electrode wear ratio (EWR) and smooth surface roughness (SR) should be the outcome at the final. The electrical discharge machining (EDM) is a non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharge between the tool that called as electrode and the other part been machined in the presence of the dielectric fluid (C.J. Luis et al., 2005). Traditional machining techniques on Titanium Alloy are often unable to economically machine with precise design required. Hence, electrical discharge machining (EDM) is the most effective machining technique to be used for this purpose.

The electrical discharge machining (EDM) is the machine that has distinct advantages over other machining process and so its use is getting more and more widespread. By using this Taguchi method, the design of experiment to produce the titanium alloy while optimize the machining characteristics will be conduct. In order to have a good machining characteristic, once need to select the proper machining parameters.

Moreover, by the Design of Experiment (DOE) using the Orthogonal Array is use to optimization of the single response characteristic. Consequently, Analysis of Variance (ANOVA) and the F value is also used to determine the significant machining parameter and obtain optimal combination levels of machining parameters. Therefore, some investigate needs to be for getting the best solution of the product by using the electrical discharge machining (EDM). The generally, the expected result that have been found that the higher material removal rate (MRR), the lower electrode wear ratio (EWR), better surface roughness and also no secondary machining.

1.3 PROBLEM STATEMENT

Taguchi methods have been used to design the experiment for finding the optimal parameter that can use and not complex way to use. This is because, EDM machine has poor machining rate or performance due to the material removed rate (MRR) characteristics, that important of the efficiency and cost effectiveness of the EDM process. The less material removed rate (MRR) is occurring in this machining process therefore it will waste and production not good. Second problem involved is an electrode wear ratio (EWR) characteristic. The electrode wear ratio (EWR) is not suitable when it is higher and it will affect the accuracy of product. (EWR) will decreases the accuracy of the product it also maybe because of the (MRR) is not suitable.

When the surface roughness (SR) condition is not in good quality will give other effect to the secondary machining that also influence by the fast material removed rate. Moreover, the (MRR) that need must be higher but the surface roughness (SR) is smooth. Besides that, the secondary machining also effect to this project it will produce product with error such as taper.

1.4 OBJECTIVE

The objective of this project is to

i. Optimize the machining parameters with EDM on Titanium Alloy using Taguchi method
ii. To analyse this project according to higher material removed rate (MRR), lower electrode wear rate (EWR) and lower surface roughness (SR)

iii. To defined the better method for Design of Experiment (DOE) by compare the Taguchi Method and the RSM method

1.5 PROJECT SCOPE

The research scope is limited to the machining parameter that will refer to the electrical parameter on EDM machining such as polarity, peak current, pulse-on time, pulse-off time, servo voltage and others. By using the copper as the tool and titanium alloy as a product the data that have been analyse by using some method. The optimization is the process to present the relationship between parameter using one-way (or one-factor) analysis of variance. The calculation will include for analyse the machining parameter such as maximum MRR, minimum EWR, and smooth SR and prevent secondary machining.

Therefore, the result for the optimization of the machining parameter will be select and it can get the most efficiency result. The quality still need to be maintain or improve, cost will reduce and other advantage and the better method of the design of experiment that can be used for the future.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are many type of the test can be approach for the experiment. The most frequently use is the full factorial experiment. However, there are possible combination that must be test but, it will take are very long time and use higher cost to conduct because of the factor use. The Robust design have design the Taguchi method for the important aspect and tool. Therefore, the engineering methodology of the Robust design have to use for obtain the product and process condition. This method have been use because of the high-quality product but the development and manufacturer cost is low the other method (J.A. Ghani et al.,2004) The Taguchi method has be uses to approach for single optimizing characteristic. The Orthogonal array is use to optimization the complicated performance characterises and from the data it will decide the optimal process parameter that selected. Besides that, when experiment in progress the dielectric fluid have constant with the pressure from the flushing and if dielectric fluid is too much also will affect the product that will produce. Improper flushing also can reduce removal rate due to unstable machining condition and arcing around regions with higher concentration (S.H Lee and X.P Li, 2001). Therefore the poor characterises will occur if the factor that influence not be aware.

The Electrical Discharge Machining (EDM) is use because of the process that shaping hard metals, also forming deep and can shaping complex-shape holes by arc erosion in all kinds of electro-conductive materials. Besides, EDM process that involved a transient sparks discharges immersed in a dielectric fluid between the electrode or tool and product (C.J. Luis et al., 2005). It have small gap between it and when the discharge occur it will melt and it remove material from the product shape according the tool shape. The EDM machining uses short duration and high current density when the process remove material between the electrode and the product also EDM not uses any physical cutting force during that process (S.H. Lee and X.P. Li, 2001). The electrodes that have be uses is copper because of this material have high temperature and excellent electrical also thermal conductivity. Thus, the electrode fabricates at high temperature and pressure (H.C Tsai et al., 2003).

The EDM will not affect the hardness and the strength of the material during the cutting process (S.H. Lee and X.P. Li, 2001) but it will low the material removal rate (MRR), higher electrode wear ratio (EWR) and worse surface roughness (SR). Therefore, the (MRR) and (EWR) are the major influence. The performance characteristics for the material removal rate (MRR) should be higher-the-better and for electrode wear ratio (EWR) and surface roughness (SR) are the lower-the-better for the machining.

The titanium alloy have called as “difficult to machine” material because of the poor thermal conductivity and coefficient of the thermal expansion that make the material difficult to cool down the heated and melted work. From this situation, it will affect the material removal rate and the machining surface will be damage (Lin Gu et al., 2012). In this project, EDM will be user to cut titanium for optimizing MRR, EWR and SR

2.2 ELETRICAL DISCHARGE MACHINE (EDM)

Electrical Discharge Machining (EDM) is the one of the non-traditional manufacturing process (C.J. Luis et al., 2005). It the important manufacturing process for the tooling, mould and die industries for several decades. There are two type of EDM machining which is die sinking EDM and wire EDM. The Electrical Discharge Machining (EDM) controlled the metal removal and usually to erode the workpiece, the shape corresponding to that of the tool electrode. From the Figure 2.1, there are about the EDM machine that commonly will discuss and it related between this four different major areas (K.H Ho and S.T Newman, 2003).

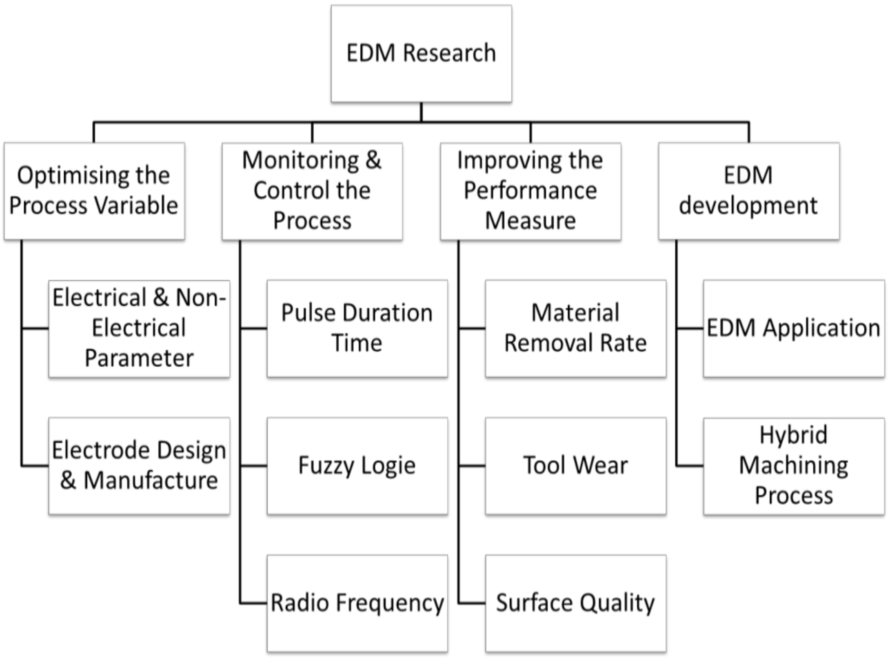

Figure 2.1: Classification of major EDM research areas
Source: K.H Ho and S.T Hewman 2003

Moreover, the EDM common dielectric fluid that usually uses are mineral oil, kerosene, paraffin, distilled water and deionised water which is non-conductor of electricity. The EDM does not make direct contact between the electrode and the workpiece. Besides, it also pumps through the arc gap to flush the material after the cutting. The dielectric fluid involve to clear and low viscosity fluid to make cleaning easier (Norliana Mohd Abbas et al., 2012). The material process at the EDM machine with any hardness can be cut as long as the material can conduct electricity (Norliana Mohd Abbas et al., 2007). Copper is commonly used by the industries, cheaper, and produces good surface finish. Besides that, copper also is a stable material under sparking conditions and gives good surface finish, low diameter overcut, high MRR, and less EWR when machining hardened tool (Norliana Mohd Abbas et al., 2012).

Besides, the electrical discharge machining (EDM) process by using the electrical current which can generates spark erosion between the electrode and the workpiece (P.M. Lonardo et al., 1999). Before do the analysis the process for both electrode and the workpiece will submerged in a dielectric fluid with the fixed small gap or will called as spark gap. The titanium alloy is known as the difficult to cut material but by using the EDM it can be machined effectively. The EDM machine also needs the flushing of dielectric fluid, it will affect the material removal rate (MRR) and the same time influences the surface roughness (SR). The different properties of the dielectric fluid also play a vital role in flushing away debris from the machining gap (K.H. Ho and S.T Newman, 2003). In this project the flushing that will use is kerosene.

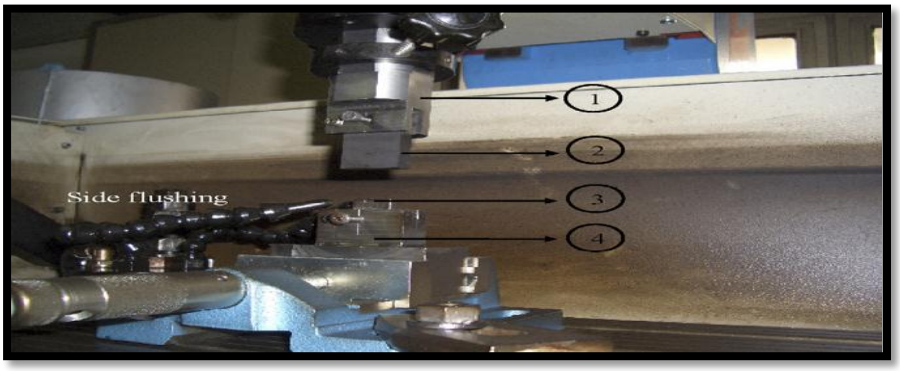

Figure 1.2: Sample of EDM figure. (1) tool holder, (2) electrode, (3) workpiece, (4) workpiece holder
Source: Hascalik and Caydas, 2007

2.3 PROPERTIES OF THE MATERIAL SELECTION

For analysis the optimization of the EDM machining performance, the electrode or tool that been choose is copper. This is because the performed of the cooper is better than graphite electrodes in term of tool wear, surface finish, and tool with positive polarity give higher material removal rate and lower tool wear ratio (S.H. Lee and X.P Li, 2001). The application of the injection flushing is pressure flushing. If it was improper flushing such as wrong selection of the flushing method during the EDM machining, it will insufficient flushing pressure during the machining process it would contribute to erratic cutting, poor machining rate (S.H. Lee and X.P Li, 2001). The proper flushing method is difficult to get the good surface roughness, higher material removal rate and electrode wear ratio also lower secondary machining. During experiment, the flushing brings fresh dielectric fluid (A. Hascalik et al., 2007) which is kerosene into the gap and cools the electrode and workpiece. However, the deeper the cavity and hole will produce the greater the difficulty for proper flushing

Titanium Alloy that using in biomedical application, marine application, and sure in automotive application especially during this experiment that for the valve it consists of two phase of alpha –beta phase of Ti6Al4V alloy (Lin Gu et al., 2012). The EDM process offer a viable and competitive alternative to machine titanium alloy because of the temperature use during the discharge process is much higher than the melting point of all material. Titanium alloy exhibit very excellent technique properties especially in term of strength, hardness and toughness. The analysis of the EDM machining performance have to make because of there will have some problem with the product such as side wall tapering therefore the product produce have not accurate dimension. When the problems occur, it will affect the cost for production, quality of the product, time taken to produce product and more. The properties show in Table 2.1 show below:

Table 2.1: Physical properties of material

Property	Titanium Alloy	Copper
Density (g/cm^3)	4.04 - 4.42	8.904
Melting point (°C)	1649±15	1084.6
Specific heat (J/g.K)	0.56	0.385
Thermal conductivity (W/m.K)	7.2	400
Electrical resistivity (μΩ.cm)	170	1.678
CTE* linear (μm/m.°C)	8.6	16.5

CTE* coefficient of thermal expansion

Source: Lin Gu et al., 2012

In this table show that for this project the Titanium Alloy will be the workpiece and the copper as an electrode or tool.

2.4 DESIGN OF EXPERIMENT (DOE)

The parameter has been performed by many researches but usually it not considers both (DOE) and mathematical formula (ANOVA). Besides that, Design of Experiment (DOE) is using to optimize the machining characteristics by using Orthogonal Array (OA) and then use Analysis of Variance (ANOVA) for analysis. By using Taguchi method, the control factor table is used as reference guide to start and execute experiment. It is the powerful tool for parametric design of performance characteristics to determine optimal machining parameter for get better machining characteristics. There are some factors that (Yaakob, 2008) :

1. Non-electrical Parameter
   i. Injection flushing pressure
   ii. Rotational od speed electrode
2. Electrical Parameter
   i. Peak current
   ii. Polarity
   iii. Pulse duration
   iv. Power supply voltage

Therefore, from all machining parameter there will choosing some of that to control the experiment. In this project the parameter that be use are peak current, pulse-on time, pulse-off time and servo voltage.

Moreover, the Orthogonal Array that required that can be considering between L_9 and L_{18} from the standard Orthogonal Array for this experiment. There will consist of 2-level and 3-level which is representing of the level that preference to the minimum, median and maximum that influence for all machining parameter. For name of this common orthogonal array is the L_9 will present for L_9 (3^4) and L_{18} will present for L_{18} $(2^1 x\ 3^7)$. The array is called orthogonal because the level of the various factors is balance and can be separated from the effect of the other factor within the analyses. However, there will have nine numbers of experiments in the orthogonal array during the project with four machining parameters have been selected where according to the Taguchi method design, L_9 orthogonal array table with the 9 rows that represent the number of experiment. Table 2 shows orthogonal Array standard use:

Table 2.2: Standard Orthogonal Array

Orthogonal array	**No of row**	**Max no of factor**	**Max no of column at these level**			
			2	3	4	5
$\boldsymbol{L_4}$	4	3	3	-	-	-
$\boldsymbol{L_8}$	8	7	7	-	-	-
$\boldsymbol{L_9}$	9	4	-	4	-	-
$\boldsymbol{L_{12}}$	12	11	11	-	-	-
$\boldsymbol{L_{16}}$	16	15	15	-	-	-
$\boldsymbol{L_{16}}$	16	5	-	-	4	-
$\boldsymbol{L_{18}}$	18	8	1	7	-	-
$\boldsymbol{L_{25}}$	25	6	-	-	-	6

Orthogonal Array is the experiment layout for the machining parameter that wills analysis using the Taguchi Method which is Robust Design. The Taguchi Method is the system of cost-driven quality engineering that emphasizes the effective application of engineering strategies rather than advanced statistical techniques (T. Rajmohan et al., 2012). The method provides simple, efficient, and systematic approach to optimize the performance in the experiment. Normally when we do full factorial design, 3^4= 81 experiment if for L_9 have been use will run during that time but it will give effect to the experiment cost prohibitive and unrealistic (T. Rajmohan et al., 2012) same to L_{18} orthogonal array. That why, the Taguchi Method have been choose to use for then parameter design. The orthogonally of is an orthogonal array experiment is not lost by keeping one or more empty column.

When design of experiment, the levels that be used for each factor is the important phase in planning. If use 2-level factor are used, the linear function will fit. When use 3-level factor the quadratic function or curve will fit and same goes to 4-level factor that fit a cubic function. This effect of the number of factor can be seen on the response graph for the MRR, EWR and SR The Taguchi method will measure the performance by record the signal to noise (S/N) ratio from the result where the signal represent the desirable value (mean) and noise represent the undesirable value (standard deviation from mean) for output characteristic (A. Adnani et al.,2010). The S/N ratio are different according to the type of the machining characteristic where for the MRR bigger are better, EWR and SR are smaller are better which defined with different formula.

All of parameter has different influence on the machining performance and the significant parameter will be found using (ANOVA). The relative important of the cutting parameter with respect to MRR, EWR and SR and it investigate using analysis of variance (ANOVA). ANOVA represent the relationship between the parameter with overall process performance. The ANOVA is the simple idea for introduces the no way (or no-factor) analysis of variance and built up to one-way (or one-factor) analysis of variance and eventually to a multi-way (or multi-factor) analysis of variance using the orthogonal array. Moreover, according the graph response for MRR, EWR and SR we can get the F test by using ANOVA equation. Therefore, the significant machining parameter and optimal combination level can be determined.

There are some of the evaluated of performance can be express by using calculation (C.J. Luis et al., 2005) which is:

1)For material removal rate (MRR) can be express as: (2.4.1)

$$\textbf{MRR(g/min)}= \frac{\boldsymbol{WRW}\ (\boldsymbol{workpiece\ removed\ weight})}{\boldsymbol{T}\ (\boldsymbol{period\ of\ machining\ time\ in\ minuter})}$$

2)For electrode Wear Ratio (EWR) express as : (2.4.2)

$$\textbf{EWR (\%)} = \frac{EWW\ (\ elecrode\ wear\ weight)}{WRW\ (\ workpiece\ removed\ weight)}\ \textbf{x 100}$$

3)For surface roughness it calculate by using the surface roughness perthometer

In this analysis, give the attention to the quality characteristic that will included such as higher-the-better (HTB) and lower-the-better (LTB) that needed to see at the machining characteristic such as MRR, EWR and SR. The material removal rate will be the higher the better and for electrode wear ratio and surface roughness need to be lower the better performance response at the final result from the analysis.

Lastly, when do the Design of experiment, based on the experiment result we will do the response graph for Material Removal Rate (MRR), Electrode Wear Ratio (EWR) and Surface Roughness (SR) follow by the each factor. From the graph the choosing level will be select by following the machining characteristics that what higher MRR, lower EWR and lower SR. The data analysis from the Taguchi approach using the Minitab software has been selected to obtain the regression and also graphical analysis. (A. Adnani et al., 2010)

2.5 DESCRIPTION OF PARAMETERS

Sentence descriptions of the parameter that can be optimize:

i. Pulse on duration and pulse interval – amount of time current runs into the gap before turn off. Each cycle has an on-time and off-time, the duration of this pulse and the number of cycles per second (frequency).
ii. Discharge Current – direct current through ionized medium.
iii. Dielectric Liquid Pressure – pressurized dielectric liquid flow through the electrode
iv. Polarity – direction of current flow in relation to the electrode. Have either direct polarity and reverse polarity.